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PATENT APPLICATION

of

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for a

MODULATION/DEMODULATION OF A PILOT CARRIER, AND MEANS TO PERFORM THE MODULATION/DEMODULATION

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The present invention relates to a method for transmitting data elements as defined in the non-characteristic part of claim 1, a transmitter and a receiver as defined in the non-characteristic part of claims 7 and 8 respectively, and a transmission system as defined in the non-characteristic part of claim 9.

Such a method for transmitting data elements, such a transmitter and receiver, and such a transmission system are already known in the art, e.g. from the *specifications of the ANSI (American National Standards Institute, Inc.) Standard on ADSL, the approved version of which has the reference T1E1.413-1995 and title "Network and Customer Installation Interfaces, Asymmetric Digital Subscriber Line (ADSL) Metallic Interface"*. Therein, data elements are modulated on a set of carriers. In case of discrete multi tone (DMT) modulation, these carriers have equidistant frequencies. As is indicated in paragraphs 6.9.1.2 and 7.9.1.2 on pages 46 and 58 of the above cited standard, published in 1995, one of the carriers is reserved as a pilot carrier. This pilot carrier is used for synchronisation between transmitter and receiver and is modulated by a constant signal. In a vector plane, wherein the modulation constellation is represented by a collection of points, the pilot carrier is thus represented by a single point. On the transmission medium, e.g. on a telephone line interconnecting the ADSL transmitter and ADSL receiver in the known system, the pilot carrier thus represents a sine or cosine which does not change in phase, amplitude or frequency in time (in case a guard band or cyclic prefix is added whose length does not contain an integer number of periods of the pilot tone, the pilot tone might be discontinu at the edges of the DMT symbol).

A well-known source of narrowbanded or single frequency disturbances is a radio amateur or an AM radio station, which broadcasts radio signals at frequencies close to carrier frequencies. Forward error correction techniques, well-known in the art, can reduce the effect of such disturbances on data carried

by the affected carriers. An alternative way to protect data against such interferers, proposed by Peter S. Chow et al. in *the article "A multicarrier E1-HDSL Transceiver System with Coded Modulation" from the authors Peter S. Chow, Noafal Al-Dhahir, John M. Cioffi and John A.C. Bingham published in issue N° 3 May/June 1993 of the Journal of European Transactions on Telecommunications and Related Technologies (ETT), pages 257-266,* is bitswapping: bit and energy allocations are updated so that the affected carriers carry less data bits then before. This technique requires an additional communication between transmitter and receiver.

Although data transmitted over the telephone line from the transmitter to the receiver may be protected by one of the above mentioned techniques, the presence of noise or an interferer, for instance a radio amateur signal, with a frequency in the vicinity of the frequency of the pilot carrier, may still cause an offset between the received point representing the pilot carrier in the above defined vector plane and the expected point. If this offset in the vector plane is not sufficiently random, it biases the synchronisation mechanism, resulting in a performance degradation. This is e.g. the case if the instantaneous phase of the interferer is very slowly varying in time with respect to the duration of the DMT symbol or if this interferer is constant.

It is an object of the present invention to provide a method for transmitting data elements and related equipment of the known type, but wherein the immunity of the pilot carrier for interference is increased significantly, and consequently wherein the degradation of the synchronisation mechanism between transmitter and receiver is reduced.

According to the present invention, this object is achieved by the method for transmitting data elements defined in claim 1, by the transmitter and receiver-defined in claims 7 and 8 respectively, and by the transmission system defined in claim 9.

In this way, by modulating the pilot carrier with a non-constant signal, the pilot carrier appears on the transmission medium as a sine or cosine with non-

constant phase and/or amplitude. Demodulation of such a pilot carrier at the receiver's side, re-generates the unmodulated pilot carrier, i.e. a sine or cosine with non varying phase and/or amplitude from the transmitted modulated pilot carrier. For interference induced on the modulated pilot carrier, this demodulation has an averaging effect as will be explained in more detail later on in the description. The effect of an interferer on different states of the modulation constellation is thus averaged by demodulation. The final effect of an interferer after demodulation is far less than the effect of the interferer on one single state in the modulation constellation scheme as a result of which the transmission system according to the present invention has a significantly increased immunity for narrowband interferers, compared to the above described known system.

It is noted that the implementation of the synchronisation means can be simplified if the constellation points of the pilot carrier are well chosen, e.g. if all points have the same amplitude.

It is further to be noticed that the term "comprising", used in the claims, should not be interpreted as being limitative to the means listed thereafter. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

Similarly, it is to be noted that the term "coupled", also used in the claims, should not be interpreted as being limitative to direct connections only. Thus, the scope of the expression "a device A coupled to a device B" should not be limited to devices or systems wherein an output of device A is directly connected to an input of device B. It means that there exists a path between an output of A and an input of B which may be a path including other devices or means.

A remark is also that, in view of the present invention, it is not important whether the frequency of the pilot carrier is a fixed one or not. The pilot carrier may change in frequency whenever the transmitter or receiver concludes that the

pilot frequency is laying within a frequency band with too much interference. The transmitter and receiver then have to negotiate a new pilot tone frequency. More details about this technique are irrelevant in view of the present invention but it is stressed here that changing the frequency of the pilot tone and modulating the pilot tone with non-constant signals are two techniques which may be applied independently to improve interference immunity of the synchronisation between transmitter and receiver. These techniques may be used complementary or may be applied separately.

In a particular implementation of the present invention, the pilot carrier is modulated as defined in claim 2.

In this way, by modulating a randomised signal on the pilot carrier, the state of the pilot carrier in the constellation scheme will change randomly so that the demodulation will have a good averaging effect resulting in an increase of the interference immunity.

In another implementation of the present invention, the pilot carrier is modulated with a predefined sequence that ensures sufficient alternations of the states of the pilot carrier, as defined in claim 3.

In this way, if the averaged effect of interference over all visited states in the constellation scheme is zero after demodulation, the best results will be obtained in terms of improvement of the interference immunity. Indeed, when each state has an equal probability and the constellation has a symmetry around zero, the effect of interference will be compensated for completely after demodulation. As an example, the constellation might contain only two points with the same amplitude but with opposite phases. Successive pilots would then have alternate phases.

It is remarked thet the proposed technique can be used whether or not the predefined sequence is known at the receiver. If the sequence is unknown, the receiver has to demap the received pilot, i.e. it has to map the received point on a constellation point. The decision is then used to generate the unmodulated pilot.

In yet another implementation of the present invention, the pilot carrier is modulated as defined in claim 4.

This implementation has the additional advantage that it provides an enlarged bandwidth for transport of data elements. Indeed, in the already cited ADSL system for instance, the pilot carrier may be modulated with an 8 kbit/s datastream by allocating two bits to it. If this additional bandwidth is used for transporting data elements, the aggregate bitrate between transmitter and receiver will be increased with an equivalent amount. It is to be remarked that, to have significant immunity against interferers, the data elements which are modulated on the pilot carrier, have to be sufficiently random so that the pilot carrier reaches all states in the constellation scheme and a good averaging of the interference is obtained by demodulation. This can be obtained by scrambling.

An additional feature of the present invention is that it may be applied in the field of ADSL and VDSL as indicated by claim 5.

Indeed, systems wherein data elements are transmitted over copper telephone lines such as ADSL (Asymmetric Digital Subscriber Line), VDSL (Very High Bitrate Digital Subscriber Line) or the like are subjected to interference such as radio amateur signals. It is therefore likely to protect such systems with the technique according to the present invention.

Furthermore, a characteristic feature of the present invention when applied in the field of ADSL, is defined in claim 6.

As described in the already mentioned ADSL specification, the DMT symbols contain user data and overhead data, e.g. operation channel data or overhead control channel data such as operation and maintenance commands, vendor specific commands, bit swap information, and so on. The embedded operations channel (eoc) and the ADSL overhead control (aoc) channel are described respectively in paragraphs 11.1 13.1 on pages 71 and 112 of the earlier mentioned specification. This information may for instance be modulated on the pilot carrier.

The above mentioned and other objects and features of the invention will become more apparent and the invention itself will be best understood by referring to the following description of an embodiment taken in conjunction with the accompanying drawings wherein :

Fig. 1 represents a transmission system including a transmitter TX and a receiver RX according to the present invention; and

Fig. 2 represents a constellation scheme for modulating a pilot carrier in a particular embodiment of the present invention, and illustrates the influence of interference induced on the modulated pilot carrier.

The transmission system drawn in Fig. 1 includes a first Asymmetric Digital Subscriber Line (ADSL) modem of which only the transmitting part TX is drawn, a second ADSL modem of which only the receiving part RX is drawn, and a copper twisted pair telephone line TM coupling the two ADSL modems. The first ADSL modem may for instance be located in a remote terminal and modulates data DATA to be transmitted over the telephone line TM towards the second ADSL modem which may for instance be located in a central office. Both ADSL modems respect the specifications of the ADSL Standard T1E1.413.

The transmitting part TX of the first ADSL modem contains between a data input DATA and a signal output S the cascade connection of a discrete multitone (DMT) modulator MOD and a line interface TI. In addition, pilot tone identifying means TPT are included and have an output coupled to an additional input of the DMT modulator MOD.

The receiving part RX of the second ADSL modem contains between a signal input S' and a data output DATA' the cascade connection of a line interface RI and a discrete multitone (DMT) demodulator DMOD. In addition, pilot tone identifying means RPT are included and have an output coupled to an additional input of the DMT demodulator DMOD.

In Fig. 1, an embodiment of the transmission system according to the present invention is thus drawn in terms of functional blocks : TX, RX, TM, MOD, TI, TPT, RI, DMOD and RPT. The working of each of these blocks will be

described sufficiently detailed in the following paragraphs. From this functional description, it will be obvious for a person skilled in the art of designing telecommunication devices how embodiments of these blocks can be manufactured with well-known electronic components. A detailed architecture of the contents of the functional blocks drawn in Fig. 1 hence is not given here.

In the transmitting part TX of the first ADSL modem, data DATA are applied to a data input DATA of the modulator MOD to be modulated thereby on a set of carriers. It is noticed that in Fig. 1, the same reference DATA is used for the incoming data and the terminal of the modulator MOD where the data are applied to. Furthermore it is remarked that the applied data DATA may be user data received from the outside world as well as overhead data, for instance bit allocation information generated inside the first ADSL modem. The modulator MOD then performs bit allocation, i.e. the modulator MOD allocates a certain number of data bits to each one of the carriers, selects an appropriate modulation type for each one of the carriers so that the right amount of bits can be modulated thereon, and then modulates the carriers. The carriers are transformed from frequency to time domain by the modulator MOD and extended cyclically so as to minimise intersymbol interference effects due to transmission over the telephone line TM. The so obtained symbols, called discrete multitone symbols, contain one carrier which is assigned to be pilot carrier and which will be used at the receiver's side for synchronisation. The modulator MOD modulates this pilot carrier in an alternating way. This means that, when 2 bits can be modulated on the pilot carrier via 4 QAM modulation, 4 different states are transmitted in an alternating way. The 4 states of the 4 QAM modulation technique are drawn in Fig. 2 and represented there by S1, S2, S3 and S4. Each of these states corresponds to a sine wave signal on the transmission line TM, and has its particular phase and amplitude. The frequency of this sine wave signal is defined by the pilot tone information means TPT. The pilot tone information means TPT may for example be a simple register containing an indication of the fixed frequency of the pilot tone, or alternatively,

may be a device negotiating with the pilot tone information means RPT in the second modem which frequency will be reserved for the pilot tone. Modulating the pilot carrier in an alternating way implies that in successive DMT symbols, the pilot carrier is represented by sine waves S1, S2, S3, S4, S1, S2, ... and so on, or by another (predefined) sequence that visits all states in an alternating way. This is different from what is specified in the draft ADSL standard. Therein, the pilot carrier should be modulated with a constant signal, e.g. (0,0) which may be represented by the point in the first quadrant of the earlier mentioned vector plane in case of 4 QAM modulation. This means that an ADSL modem, operating according to the ADSL standard, transmits one single sine, S1 for instance, in successive DMT symbols as the pilot carrier.

In Fig. 2 it is supposed that a radio amateur signal affects the pilot tone carrier in the above described embodiment according to the present invention. The interference component added to the states S1, S2, S3 and S4 in successive DMT symbols is I1, I2, I3 and I4 respectively. Instead of a sine wave whose amplitude and phase is determined by the vector P in Fig. 2, the receiver RX thus receives a sine wave whose amplitude and phase correspond to that of PI. Similarly, the sine wave received by the receiver RX in symbols wherein states S2, S3, or S4 are transmitted, differs in phase and amplitude from the transmitted sine wave in an amount determined by the respective vectors I2, I3 and I4.

The affected signal S' enters the receiving part RX of the central office modem and is applied to the line interface RI to be conditioned: transmission line coupling, front-end filtering and analogue to digital conversion for instance are performed with the appropriate levels of linearity and noise in RI. The conditioned and digitised signal then is applied to the demodulator DMOD which equalises the signal in time domain to compensate for intersymbol interference, which removes the cyclic prefix, converts the time domain signal into a frequency domain signal via fast fourier transformation and equalises the signal in frequency domain to compensate for phase and amplitude errors in the received carriers. The demodulator DMOD also regenerates the pilot carrier

from the successive states S1, S2, S3, S4. The demodulation thereto leaves S1 unaffected, rotates S2 in the next DMT symbol over 90 degrees clockwise, rotates S3 in the next DMT symbol over 180 degrees clockwise, rotates S4 in the next DMT symbol over 270 degrees clockwise, and so on. All states are thus rotated to the first quadrant so that a continuous pilot carrier at the frequency indicated by the pilot frequency indicating means RPT is constituted. Due to the interference I1, I2, I3 and I4 induced on S1, S2, S3 and S4 respectively, the sine wave in successive DMT symbols representing the pilot carrier, differs in phase and amplitude from the originally transmitted phase and amplitude determined by the vector P. When turned back to the first quadrant, the phase and amplitude of the sine waves received in successive DMT symbols is given by the vectors P+I1, P+I2', P+I3' and P+I4'. As is seen from Fig. 2, the interference component induced on S1, i.e. I1, compensates for the interference effect I3' induced on S3. Similarly, the interference induced on S2, i.e. I2', compensates for the interference effect I4' induced on S4. Regenerating the pilot carrier in the demodulation DMOD and averageing over successive DMT symbols thus reduces the effect of the interference, if the pilot carrier is transmitted over the transmission line TM as a sequence of alternating modulation states. Theoretically, the pilot carrier can be regenerated perfectly so that synchronisation between the transmitter TX and receiver RX is not disturbed by the radio amateur. As a consequence, the data DATA' can be retrieved by demodulation of the other carriers in a perfect way.

A first remark is that, although the signal S in the above described embodiment is transported over a telephone line TM, the applicability of the present invention is not restricted by the transmission medium via which the signal S is transported. In particular, any connection between the transmitter TX and receiver RX, e.g. a cable connection, a satellite connection, a radio link through the air, and so on, may be affected by narrowbanded interference, and thus can be protected by the method according to the present invention. The invention also is not only related to ADSL (Asymmetric Digital Subscriber Line) or

similar systems wherein DMT (Discrete Multi Tone) modulation is used. A person skilled in the art will be able to adapt the above described embodiment so that it is applicable to any other system wherein a pilot carrier is transmitted from transmitter TX to receiver RX for synchronisation purposes. *US 5,546,190* for instance describes an optical communication system wherein a pilot tone is multiplexed with multiple subcarriers, having frequencies which are integer multiples of the pilot tone frequency, and *US 5,548,344* describes an HDTV system wherein a pilot sine wave signal is multiplexed with the HDTV carriers.

Another remark is that the origin of the narrowbanded interference is of no importance for applicability of the present invention. Whether the disturbing signals are transmitted by a radio amateur, as supposed in the above described example, by a taxi, by the police, or are originating from yet another source is not relevant. Whenever the transmitter TX expects that the pilot carrier may be affected by an interferer, he can protect the synchronisation between transmitter TX and receiver RX by modulating the pilot carrier.

It is noticed that in an alternative embodiment, the pilot tone is modulated randomly instead of in an alternating way. This means that, referring to Fig. 2, a random sequence of the states S1, S2, S3 and S4 is transmitted instead of a predetermined alternating sequence.

In yet another alternative embodiment, the pilot carrier may be modulated with scrambled data. Scrambling part of the data DATA in Fig. 1 has a randomising effect. Such randomised data then may be modulated on the pilot carrier. Since the states S1, S2, S3 and S4 will randomly be transmitted, demodulation in the receiver and averageing will again reduce the effect of the induced interference. Apparently, the latter embodiment has the advantage of an increased capacity, since the bandwidth occupied by the pilot carrier also is used for transmission of data. In case of ADSL transmission, overhead information such as the aoc-data or eoc-data may be used to modulate the pilot carrier.

While the principles of the invention have been described above in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention.